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DUST CONTROL ON CONSTRUCTION SITES

State of the Art

Final Report

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16. ABSTRACT

Dust control of construction sites is a major concern for ADOT in regard to environmental and air quality problems in the hot dry climate experienced by Arizona's large metropolitan areas. A literature review of dust control agents and/or processes was conducted to aid in the formulation of a plan to select products as possible alternatives to ADOT's current practice of dust control, constant watering. A summary of the mechanism of dust control is presented as well as a range of estimated engineering properties of soils in the Phoenix metropolitan area. A summary of laboratory and field testing of various products is presented. Cost estimates were calculated with the conclusion that the use of dust control agents on construction sites warrants field evaluation.

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INTRODUCTION AND OBJECTIVES

Dust control of construction sites can be a major environmental and air quality problem in the hot dry climate of the Phoenix metropolitan area.[a,13] Constant watering is the predominant, if not the only, method used to reduce dust quantities arising from construction sites; a practice which may be fairly expensive in an area where water can be at somewhat of a premium. Watering may also be equipment and labor intensive, yet may sometimes be ineffective in dust control on quiescent areas, as well as equipment routings.

The primary objective of this report is to provide (1) a literature review of dust control agents and processes, and (2) to consider the feasibility of selected palliatives and/or in-situ mixed-in-place admixtures, as possible alternatives to constant watering of construction sites.

Palliatives may provide only short term effectiveness on equipment routings, but may provide long term effectiveness on quiescent regions such as completed borrow areas. In-situ mixed-in-place admixtures normally provide longer term effectiveness on equipment routes, such as a primary haul-road. Thus both long and short term dust reduction measures are included as a part of this review and analysis.

Soil characteristics affect palliative product and/or admixture usage and effectiveness. Consequently a review of soil types in the Phoenix Valley area was conducted, and is summarized herein.

Recommendations on palliative/admixture alternatives for use in the area are presented herein, while the merits of conducting field test sections of such alternatives should be a foredrawn conclusion. However, development

[a]Dust has been shown to be a carrier of airborne pulmonary disease emanating from animal carcasses in the soil of arid regions [1].

of a "detailed field investigation workplan, estimated budget, anticipated impact statement and implementation objective," cannot be fully achieved without further knowledge of specific site, or sites, soil characteristics, construction plans, or processes.

SUMMARY OF MECHANISM OF DUST CONTROL

Two primary application methods are commonly used for dust control: (1) surface or topically applied spray for both quiescent or travelled areas, and (2) mixed-in-place as a thin surface improvement for travelled areas only. Mixed-in-place, while initially somewhat more costly, may achieve longer term palliation, improved surface characteristics, and reduced maintenance costs; the latter due to potential elimination of subsequent periodic replacement [9].

Dust from a quiescent area originates from activation of silt, clay, and colloidal particle sizes by wind; i.e., wind erosion. If of great enough velocity, wind will also transport sand and/or finer aggregate sizes. However, the smaller the particle size, the longer the distance transported, and the greater the turbulent plume of dust both vertically and horizontally from the source. Dust analyses have shown conclusively that selective sorting is operative, and is size-selective rather than specific gravity-selective [9,16].

Dust from a roadway originates from either a degrading aggregate or a lack of stability of flocculations of silt, clay, and colloidal size particulates; degradation of the aggregate, or floccules of aggregated fine particulates, being generated by vehicular abrasion and loadings. Once abraded or degraded, fine particulates are then airborne by either traffic generated turbulence or on-site winds.

Ambient levels of atmospheric deposition of dust have been suggested as 1.5 pounds/acre/day of particulates [6]. A study of dustfall from several unpaved roads has shown a range of less than one to in excess of 700 pounds/acre/day/100 vehicles of traffic, with significant above-ambient levels of dust occurring in excess of 640 ft from the traffic-generated sources [4,5]. Median particle diameters determined within the same study ranged from 2 to 39 microns (0.002 to 0.039 mm) with the finer particulates being carried further from the source. A 1979 EPA report based maximum ambient air quality standards as 75 micrograms/cubic meter for particulate concentrations [7]. Thus, airborne dust is of very small size, with median grain sizes of 10 microns or less being of major interest for environmental and health considerations [13].

An effective dust palliative, and/or chemical soil stabilization agent, must therefore provide a stable flocculation, or aggregation, of fine particulates, at least increasing stable particle sizes for prevention of wind/traffic movement of finely sorted sizes. Water is a temporary means of providing particulate flocculation through what might be termed capillary cohesion. Water existing between adjacent soil grains creates a tensile force due to coupling of the particles by an annular ring of water and an accompanying negative pore water pressure. This tensile force is a function of surface tension and ring geometry, the latter dependent on grain shape and moisture content [15]. Because of increasing curvature of the annulus, the tensile force increases as the soil becomes drier. A limiting value of the negative pressure is the vapor pressure of the water solution, which may be very high in clayey soils and produces a rather hard clod, thus increasing stability except under abrasive forces. In fine sands, the soil dries, but the tensile forces drop to zero, leaving loose, unbonded sand particles.

A corollary to surface tension mechanisms is the use of deliquescent and hygroscopic products as dust palliatives, such as calcium chloride and lignosulfonates. Deliquescents absorb moisture from the air, the moisture then tending to provide changes within the capillary tensile forces. Hygroscopic products initially retain lay down moisture which is slowly dissipated and may often form a crust like surface patina; the patina generally being susceptible to loadings and abrasion, as well as rainfall. Some commonly used deliquescent/hygroscopic products however may provide unwanted side effects. For example, they may be highly acidic, thus requiring (1) special handling during shipping and construction, or (2) causing corrosion if in contact with certain metals. In addition, the useful life of such products is either spent after the first rain or the soil surface becomes quite slick. Such products have often been noted to be transported into groundwater or streams, and may also adversely affect vegetation.

Some palliative/stabilization agents tend to concentrate in air-water interfaces, modifying dipolar attractions of the water molecules and thus changing the surface tension, or capillary cohesion. If surface tension should be decreased, such action tends to disperse floccules of fine particulates, whereas if surface tension is increased, the fine particulates are more readily flocculated, and thus more resistant to becoming airborne.

Most fine grained particulates carry a net negative charge, some more than others, and occasionally dependent on their mineralogy. Through the addition of positively charged additives, the negatively charged particles may be flocculated, or bonded electrostatically. These electrostatic forces can be relatively light or extremely tenacious dependent on the physico-chemical properties of both the product and the soil particles. This is a principle of several forms of chemical stabilization, as well as stabilization with some salts, polymeric compounds, and emulsified asphalts. To assure compatibility of the soil and product requires more than general classification and strength tests, since compatibility may be more dependent on measurement of such soil values as surface area, zeta potential, and cation exchange capacity.

Some forms of polymeric compounds, emulsified plastics, and emulsified rubber-like compounds may enmesh soil particulates in a manner similar to root growth of plants [8]. Successful spray-on applications of such products may be highly dependent on (1) compatibility of the physico-chemical properties of both product and soil particulates, and (2) density of the surface to which the product is applied. In the latter regard, if the surface is dense, no penetration may be achieved and only a crustal patina of product may be formed; a condition readily disturbed by any vehicular movement. However, where a relatively porous surface is available, where the surficial soil is relatively loose, or where the soil may be of a single-grained structure, the water carrier of such products will often transport portions of the product to a depth of up to 1.5 to 2.0 cm. Upon drying, the matrix or rootlike enmeshment may then be formed.

As may be noted from this brief summary, silt, clay, and colloidal particles, i.e., those particles smaller than the No. 200 U.S. standard mesh, are the primary particulates that may be suspended in air, and thus need environmental control. Adoption of spray-on, penetration, or mixed-in-place applications of dust control products may be dependent on:

(1) Time constraints in relation to permanency of control,

(2) Quiescent or construction oriented activities,

(3) Densification and/or porous nature of the soil surface to which applied, and

(4) The compatibility of physico-chemical and electrostatic properties of both the soil and products.

Whatever product may be selected for a specific soil type, its primary functions must be to provide a stable flocculation/aggregation or matrix enmeshment of the silt, clay and colloidal size particulates for prevention of airborne transport [5].

ESTIMATE OF SOIL PROPERTIES OF PHOENIX METROPOLITAN AREA

In order to consider a dust control strategy, or strategies, an evaluation of soil types found in the Phoenix Metropolitan area was made from two U.S.D.A. soil surveys of Maricopa County [2,3]. In general, the area was approximately bounded by a line from Surprise through Litchfield Park and Avondale on the west, Gila River Indian Reservation through Chandler and Higley on the south, Higley to Salt River Indian Reservation on the east, and Salt River Indian Reservation through Lookout Mountain and Surprise on the north. No data were available however, for the areas encompassing both Gila River or Salt River Indian Reservations.

Most soil information covered in agricultural soil surveys is only generalized to depths of about 5-6 feet from the surface. However, this is usually adequate to at least estimate material properties into the upper portions of the parent material for those soils which may be generally deeper than the 5-6 feet surveyed by U.S.D.A.

Soils differ in a region due to variations in five primary factors that govern their formation. Such factors are topography, climate, vegetation/organisms, parent material, and time. While climate and vegetation generally provide regional differences, topography, parent materials, and time, affect local variations.

Climate of the Phoenix region is warm, arid to semi-arid, with an average annual rainfall of 6-8 inches and low humidity [2,3]. Snowfall is rare in the valley regions, though light dusting may occur in the mountains above 2500 ft elevations. Frost or freezing temperatures are also rare in the region. Short-lived gusty winds are common during stormy periods or passage of low-pressure troughs. Climate influences vegetation, the rate at which organic matter builds or decomposes, weathering rates of minerals, and the nature of the weathered products and/or removal or accumulation of minerals in the soil profile. Though rainfall is low, enough moisture is available for weathering of minerals and formation of silicate clays, but is generally inadequate to rapidly leach or move clays and carbonates into lower reaches of the profiles. The upper reaches of many profiles may contain carbonates, thus providing general alkaline soil conditions. Where used, irrigation has tended to increase alkaline and calcareous salts in many of the profiles.

Without irrigation, the high temperatures and lack of moisture favor rapid oxidation and destruction of organic matter/decaying vegetation. Under such conditions, most soils of the region contain less than 0.5% organic matter, many less than 0.1%. Where plant cover was originally sparse but irrigation has been utilized, organic matter contents have increased to near 1%, and in a few profiles may have reached 1.5%. Where muddy irrigation water has been used, silt, clay, organic matter, and salts have been deposited in the upper soil profiles. Organic matter content affects most dust control and soil stabilization products, tending to reduce the soil/product composite's effective aggregation/flocculation ability.

Parent material is the unconsolidated material and/or weathered rock in which a soil forms. Parent material in the Phoenix region has been transported and deposited by water, or residually formed over, or adjacent to, hard bedrock. Thus the bulk of the soils of the region are derived from alluvium, or in limited instances from colluvial and residual sources. Transport of alluvium has been associated with the major streams of the area, the tributaries thereof contributing lesser amounts of alluvial development. Alluvium of the region is both old and recent, and in some profiles is a depositional intermixture of the two. Soils have also developed on alluvial fans from nearby mountains and may also be old or recent. In some valleys, younger alluvial fans are encroaching on older materials of the valley. Wind transported silts are a minor source of soils in the area, but are generally reworked by water for incorporation into the alluvial deposits.

Particle hardness, porosity, particle size, mineralogy, and potential weatherability of the parent soils are variable, and dependent on source derivation. Most of the soils are derived from a wide mixture of igneous, metamorphic, and sedimentary rock from a variety of sources and geologic ages. Most of the soils have been derived from granite-gneiss, basalt, granite, schist, tuff, andesite, rhyolite, and limestone rock formations.

Topography influences soil formation through its effect on moisture, erosion, and temperature. Much of the Phoenix region is characterized by broad, featureless valleys. Landforms of the region are mountains, low hills, alluvial fans at mountain bases, valley plains, low stream terraces, and flood plains in or adjacent to the major stream channels. Elevations range from about 750 to 1600 ft, with the mountains being up to about 3500 ft [2,3]. Erosion has been active, some steep alluvial fans being the most active. Gently sloping alluvial fans continue to receive some deposition during major storms, but convex-shaped slopes are more erodable, producing more runoff, and are less leached of calcareous or alkaline products than flatter or concave-shaped slopes. Some silts are wind deposited on north and east facing mountain slopes, since rainfall and plant growth are somewhat more effective thereon, and temperatures are somewhat cooler.

Soils of the region range from very old to very young in their development, being partially dependent on stability of the surficial materials. Fresh sediments may occur during periodic flooding in stream channels or on flood plains, and the soils therein may be quite young in their development. Older soils may show slight to considerable effervescence when treated with hydrochloric acid, with carbonate concretions (calcium carbonate with occasional magnesium carbonate) being relatively non-existent, to well defined. Parent soils of the region may therefore have been in place for but a few, to in excess of 7,000 years [2,3].

Table 1 presents the general range of estimated engineering properties of soils in the Phoenix metropolitan area, boundaries of which were previously described [2,3]. Soils are listed in accordance with U.S.D.A. Soil Series names [2,3]. Several series are not listed, since they are extremely heterogeneous. For example, such series would include the Rock Land and Rough Broken Land, soils that are predominantly gravelly to rock rubble, and exist on strong slopes at higher elevations.

Table 1. Range of Estimated Engineering Properties of Soils in Greater Phoenix Metropolitan Area.[a]

Soil Series	Depth from Surface, in.	USDA Texture	Classification		Coarse Fraction > 3 in., %	% Pass No. 40	% Pass No.200	Liquid Limit, %	Plasticity Index, %	Permeability, in./hr.	pH	Shrink-swell potential	Suitability as a Road Fill	Associated Landform
			Unified	AASHTO										
Agualt	0-27	Loam	ML	A-4	0	85-95	55-65	25-35	0-5	0.6-2.0	7.9-8.4	Low	Good	Floodplains,
	27-60	Sand	SP	A-3	0	55-65	0-3	---	NP	> 20	7.9-8.4	Low		low terraces,
														alluvial fans
Antho	0-60	Sandy loam or	SM	A-2	0	50-60	15-30	---	NP	2.0-6.0	7.9-8.4	Low	Good	alluvial fans
		grav. sa. lm.												str.terraces,
														floodplains
Antho (saline-alkali)	0-60	Sandy loam or grav. sa. lm.	SM	A-2,A-4	0	50-60	15-30	---	NP	2.0-6.0	8.5-9.0	Low	Good	alluvial fans str.terraces, floodplains
Avonda	0-13	Clay loam	CL	A-6	0	90-100	70-80	30-35	11-15	0.2-0.6	7.9-8.4	Moderate	Fair	Valley plains,
	13-27	Loam	ML	A-4	0	95-100	55-65	25-35	NP-10	0.6-2.0	7.9-8.4	Low		str. terraces
	27-60	Lmy. co. sa.	SP or SM	A-3	0	55-65	0-10	---	NP	6.0-20.0	7.9-8.4	Low		
Avondale	0-12	Clay loam	CL	A-6	0	90-100	70-80	30-35	11-15	0.2-0.6	7.9-8.4	Moderate	Fair	Alluv. plains,
	12-60	Loam	ML	A-4	0	85-95	55-65	25-35	NP-5	0.6-2.0	7.9-8.4	Low		str. terraces
Avondale (saline-alkali)	0-12	Clay loam	CL	A-6	0	90-100	70-80	30-35	11-15	0.2-0.6	7.9-8.4	Moderate	Fair	Alluv. plains,
	12-60	Loam	ML	A-4	0	85-95	55-65	25-35	NP-5	0.6-2.0	7.9-8.4	Low		str. terraces
Brios	0-14	Sandy loam	SM	A-2	0	50-60	25-35	---	NP	2.0-6.0	7.9-8.4	Low	Good	Floodplains,
	14-60	Sa. & grav. Sa	SP	A-1	0-5	30-40	0-10	---	NP	6.0-20.0	7.9-8.4	Low		low terraces,
														alluvial fans
Carrizo	0-5	Gr. Sa. Loam	SM	A-1,A-2	0-25	40-50	20-30	---	NP	2.0-6.0	7.9-8.4	Low	Fair	Floodplains,
	5-60	V.Gr. co. sa.	GW to SM	A-1	0-25	5-40	5-10	---	NP	> 20	7.9-8.4	Low		str.channels,
														alluvial fans
Cashion	0-27	Clay	CL or CH	A-7,A-6	0	90-100	80-95	36-55	15-30	0.06-0.2	7.9-8.9	High	Poor	Floodplains,
	27-60	Lm.-VF Sa.Lm.	ML	A-4	0	85-95	60-75	25-35	NP-5	0.6-2.0	7.9-8.9	Low		low terraces
Cavelt	0-10	Grav. Loam	ML or SM	A-4	---	55-75	40-60	---	---	0.63-2.0	---	Low	Fair	Alluvial fans,
	10	Indurated lime hardpan	---		---	---	---	---	---	< 0.06	---	---		at mtn. bases
Cherioni	0-6	V. grav. loam	GM	A-1,A-2	0-15	20-40	15-30	20-30	NP-5	0.6-2.0	7.9-8.4	Low	Poor	Low hills,
	6-12	Silica-lime cemented hardpan bedrock			---	---	---	---	---	---	---	---		lower mtn. slopes
Contine	0-12	Clay loam	CL	A-6	---	85-95	65-75	40+	20+	0.20-0.63	---	Moderate	Poor	Old alluvial
	12-38	Clay	CH	A-7	---	80-90	70-80	60+	40+	0.06-0.20	---	High		fans
	38-66	Clay lm. & lm.	CL	A-6,A-7	---	85-95	65-75	40+	20+	0.20-0.63	---	Moderate		

[a]All data in this table were taken from, or interpreted from, references 2 and 3.

Table 1. Range of Estimated Engineering Properties of Soils in Greater Phoenix Metropolitan Area.[a] (CONTINUED)

Soil Series	Depth from Surface, in.	USDA Texture	Classification: Unified	Classification: AASHTO	Coarse Fraction > 3 in., %	% Pass No. 40	% Pass No. 200	Liquid Limit, %	Plasticity Index, %	Permeability, in/hr.	pH	Shrink-swell potential	Suitability as a Road Fill	Associated Landform
Coolidge	0-24 24-60	Sandy Loam Sandy Loam	SM SC	A-2 A-2,A-4	0 0	60-70 60-70	25-35 30-45	25-30 25-30	2-4 8-10	2.0-6.0 2.0-6.0	7.9-8.4 7.9-8.4	Low Low	Good	Old alluvial fans, valley plains
Ebon	0-38 38-60	V.Cob.Clay V.Cob. Sa. Cl. Loam	GC or CH GC	A-2,A-7 A-2	30-85 30-85	20-65 25-50	15-60 15-35	41-60 30-40	20-40 11-20	0.06-0.2 0.2-0.6	7.9-8.4 7.9-8.4	Moderate Low	Good	Old alluvial fans
Estrella	0-24 24-60	Loam Clay Loam	ML CL	A-4 A-6	0 0	75-85 85-95	65-75 70-80	--- 30-40	NP 12-18	0.6-2.0 0.2-0.6	7.9-8.4 7.9-8.5	Low Moderate	Fair	Broad alluvial fans, low terraces
Estrella (saline-alkali)	0-24 24-60	Loam Clay Loam	ML CL	A-4 A-6	0 0	75-85 85-95	65-75 70-80	--- 30-40	NP 12-18	0.6-2.0 0.2-0.6	7.9-8.4 8.5-9.6	Low Moderate	Fair	Broad alluvial fans, low terraces
Gachado	0-14 14	V.gr.Sa.Cl.Loam Bedrock	GC ---	A-6,A-2 ---	5-15 ---	40-50 ---	25-40 ---	30-40 ---	15-20 ---	0.06-0.2 ---	7.9-8.4 ---	Low ---	Poor	Low hills, lower mtn. slopes
Gadsden	0-60	Clay, Cl.Loam	CH	A-7	0	90-100	80-90	50-60	25-35	0.2-0.06	7.9-8.4	High	Poor	Floodplains, low terraces
Gadsden (saline-alkali)	0-60	Clay, Cl.Loam	CH	A-7	0	90-100	80-90	50-60	25-35	0.2-0.06	8.5-9.0	High	Poor	Floodplains, low terraces
Gilman	0-60	Loam, V. Fine Sandy Loam	ML	A-4	0	75-85	65-75	---	NP	0.6-2.0	7.9-8.4	Low	Fair	Valley plains, low stream terraces, alluvial fans
Gilman (saline-alkali)	0-60	Loam, V. Fine Sandy Loam	ML	A-4	0	75-85	65-75	---	NP	0.6-2.0	8.4-9.6	Low	Fair	Valley plains, low stream terraces, alluvial fans
Gilman Variant (mod. saline)	0-28 28-60	V. Fine Sa.Lm. Silty Clay	ML CH	A-4 A-7	0 0	75-85 90-100	65-75 80-90	--- 50-60	NP 25-35	0.6-2.0 0.2-0.6	7.9-8.4 7.9-8.4	Low High	Poor	Valley plains, low stream terraces, alluvial fans
Glenbar	0-60	Clay Loam, Si.Clay Loam	CL	A-6,A-7	0	85-95	75-85	35-45	20-30	0.2-0.6	7.9-8.4	Mod.High	Poor	Valley plains, low stream terraces, floodplains

[a]All data in this table were taken from, or interpreted from, references 2 and 3.

Table 1. Range of Estimated Engineering Properties of Soils in Greater Phoenix Metropolitan Area.[a] (CONTINUED)

Soil Series	Depth from Surface, in.	USDA Texture	Classification Unified	Classification AASHTO	Coarse Fraction > 3 in., %	% Pass No. 40	% Pass No. 200	Liquid Limit, %	Plasticity Index, %	Permeability, in/hr.	pH	Shrink-swell potential	Suitability as a Road Fill	Associated Landform
Glenbar (saline-alkali)	0-60	Clay Loam, Si.Clay Loam	CL	A-6,A-7	0	85-95	75-85	35-45	20-30	0.2-0.6	7.9-9.0	Mod. High	Poor	Valley plain low stream terraces, floodplains
Gunsight	0-60	Gr.Loam, V. Gr. Loam	GC	A-2,A-1	0-15	20-30	15-20	20-30	10-15	0.6-2.0	7.9-8.4	Low	Good	Old al. fans
Harqua	0-14	Gr.Cl. Loam, Loam	CL	A-6	0	60-75	50-65	30-40	12-20	0.2-0.6	7.9-9.0	Moderate	Fair	Old alluvial fans
	14-60	Gr.Cl. Loam	SC	A-6	0-5	55-75	40-60	30-40	11-20	0.2-0.6	7.9-9.6	Moderate		
Laveen	0-60	Loam	ML	A-4,A-6	0	70-85	50-70	25-40	NP-15	0.6-2.0	7.9-8.4	Low	Fair	Old alluvial fans, valley plains, str. terraces
Laveen (saline-alkali)	0-60	Loam	ML	A-4,A-6	0	70-85	50-70	25-40	NP-15	0.6-2.0	8.5-9.6	Low	Fair	Old alluvial fans, valley plains, str. terraces
Maripo	0-34 34-60	Sandy Loam Gr. Sand	SM SM,SP	A-2,A-4 A-1	0 0	60-70 30-45	30-40 0-15	--- ---	NP NP	2.0-6.0 6.0-20.0	7.9-8.4 7.9-8.4	Low Low	Good	Alluvial fans, low str. terraces, floodplains
Mohall	0-35 35-60	Clay Loam V.F.Sa. Loam	CL ML	A-6 A-4	0 0	85-95 85-95	70-80 50-65	30-40 25-35	20-30 NP	0.2-0.6 0.6-2.0	7.9-8.4 7.9-8.4	Moderate Low	Fair	Old alluvial fans, valley plains
Perryville	0-38 38-60	Gr. Loam Sa. Loam	SM,SC-SM SM	A-2,A-4 A-2	0 0-10	40-55 55-65	30-40 25-35	25-40 20-30	5-10 NP-5	0.6-2.0 2.0-6.0	7.9-8.4 7.9-8.4	Low Low	Fair	Old alluvial fans, str. terraces
Perryville (saline-alkali)	0-38 38-60	Gr. Loam Sa. Loam	SM,SC-SM SM	A-2,A-4 A-2	0 0-10	40-55 55-65	30-40 25-35	25-40 20-30	5-10 NP-5	0.6-2.0 2.0-6.0	8.5-9.6 8.5-9.6	Low Low	Fair	Old alluvial fans, str. terraces
Pimer	0-60	Cl. Loam, Loam	CL	A-6	---	85-95	80-90	---	---	0.2-0.63	---	Moderate	Poor	Floodplains, alluvial fans
Pinal	0-12 12	Loam Indurated silica-cemented hardpan	ML,SM ---	A-4 ---	0-5 ---	65-75 ---	40-60 ---	25-35 ---	NP-10 ---	0.6-2.0 ---	7.9-8.4 ---	Low ---	Poor ---	Old alluvial fans, str. terraces

[a]All data in this table were taken from, or interpreted from, references 2 and 3.

Table 1. Range of Estimated Engineering Properties of Soils in Greater Phoenix Metropolitan Area.[a] (CONTINUED)

Soil Series	Depth from Surface, in.	USDA Texture	Classification		Coarse Fraction ≥ 3 in., %	% Pass No. 40	% Pass No. 200	Liquid Limit, %	Plasticity Index, %	Permeability in/hr.	pH	Shrink-swell potential	Suitability as a Road Fill	Associated Landform
			Unified	AASHTO										
Pinal, mod. deep variant	0-38	Loam	ML	A-4	---	70-80	50-60	---	---	0.63-2.0	---	Low	Fair	Old alluvial fans, str. terraces
	38	Indurated lime-silica hardpan	---	---	---	---	---	---	---	---	---	---	---	
Pinamt	0-22	V.Gr.Sa. Clay Loam	GM	A-2	5-40	20-40	15-30	30-40	5-10	0.2-0.6	7.9-8.4	Low	Good	Old alluvial fans at mtn. bases
	22-60	V.Gravelly Sandy Clay Loam	GM	A-1	5-30	15-30	15-20	---	NP	2.0-6.0	7.9-8.4	Low		
Rillito	0-60	Gr.Loam, Gr.Sa.Loam	SM,SC-SM	A-2,A-4	0	40-60	30-40	25-35	NP-15	0.6-2.0	7.9-8.4	Low	Good	Old alluvial fans, str. terraces
Tremant	0-23	Gr.Cl.Loam	SC,GC	A-6	0-10	45-60	35-50	20-40	10-20	0.2-0.6	7.9-8.4	Moderate	Fair	Old alluvial fans, str. terraces
	23-60	Gr. Loam	SM	A-4	0-10	45-60	35-45	25-35	NP-10	0.6-2.0	7.9-8.4	Low		
Trix	0-60	Clay Loam	CL	A-6	0	90-100	70-85	30-40	20-30	0.2-0.6	7.9-8.4	Moderate	Poor	Valley plains, low terraces
Valencia	0-26	Sandy Loam	SM	A-2	0	65-75	25-35	---	NP	2.0-6.0	7.9-8.4	Low	Fair	Valley plains, alluvial fans
	26-60	Clay Loam, Sa.Cl. Loam	CL	A-6	0	90-100	70-80	30-40	15-20	0.2-0.6	7.9-8.4	Moderate		
Valencia (saline-alkali)	0-26	Sandy Loam	SM	A-2	0	65-75	25-35	---	NP	2.0-6.0	7.9-8.4	Low	Fair	Valley plains, alluvial fans
	26-60	Clay Loam, Sa.Cl. Loam	CL	A-6	0	90-100	70-80	30-40	15-20	0.2-0.6	8.5-9.6	Moderate		
Vecont	0-60	Clay	CH	A-7	0	85-95	75-90	50-60	30-40	0.06-0.2	7.9-8.4	High	Poor	Old alluvial fans, valley plains
Vint	0-60	Loamy Fine Sand	SM	A-2	0	70-90	15-25	---	NP	2.0-6.0	7.9-8.4	Low	Good	Floodplains, low terraces, alluvial fans

[a]All data in this table were taken from, or interpreted from, references 2 and 3.

As may be seen in Table 1, the U.S.D.A. textural classification notes materials ranging from clays to gravelly coarse sands. AASHTO engineering classifications range from A-1 to A-7 with Unified classifications ranging from GW to CH, indicating an extreme variability in potential stability characteristics for roadway construction. Several soil series contain from slight to significant percentages of particles greater than 3 inch size.

Table 1 presents the general range of percentages of particle sizes passing both No. 40 and 200 U.S. Standard sieves; i.e., what would be classified as percentages of fine sand to colloidal size particles. These particle sizes represent the potential wind transportable dust, transport distances nominally increasing in relation to decreased particle sizes. Quantities of such particle sizes appear to vary from near zero to near 100%, suggesting very low to very high potentials of transportable particulates.

Graphical analysis of the range of percent passing both the 40 and 200 sieves suggested three sorted bands or groupings of materials. For example, analysis of Table 1 data suggested groupings of materials from 70-100%, 45-80%, and 5-65%. As might be anticipated, the larger percentages passing the No. 40 sieve were also actually showing greater quantities of particles passing the No. 200. Correlation coefficients for such groupings from regression analyses ranged from 0.72 to 0.95.

Taking the above groupings and analyzing liquid limits (LL) and plasticity indices (PI) for each, showed respective LL ranges of 25-60%, 20-40%, and 15-60% while the ranges of PI were non-plastic(NP)-40%, NP-20%, and NP-40%. It should be noted however, that the Ebon series increased the third grouping as an outlier due to its highly cobbly nature; otherwise LL values of the third grouping would range from 15-30%, and PI values from

NP-15%. While (1) the first grouping may have shown larger percentages of particle size passing the No. 40 and 200 sieves, decreasing with the second and third groupings, (2) in a like manner LL and PI values generally decreasing from the first to third groups, whereas (3) the quantity of NP soils from first to third groups also tended to increase, doubling from first to second, with a slight increase from second to third group.

Significance of the preceding analysis is not so much related to the grouping ranges of particle size, LL, or PI, as it is to the fact that NP materials show in each grouping of the regional soils. Plasticity index is (1) an empirical indicator of the suitability of fine grained soil particles to act as cohesive binders in a stabilized soil mixture, and (2) is an empirical measure of the cohesive properties of the soil, indicating the degree of surface-chemical activity and bonding properties of the fine clay and colloidal fractions.

When coupled with the quantity or percentage of 2μm (0.002 mm) clay, PI may also be used in determination of the activity index (AI) [10], which correlates fairly well with clay mineralogy and potential of surface chemical activity. Data on both percentage passing 2μm fraction and PI was limited to only the Cantine, Gilman, and Laveen series, with the Vint series showing only 1-3% passing 2μm, but NP for the PI values [3]. Of seven values available, the AI median and one standard deviation were determined as 1.03±0.33. While the AI data are thus extremely limited, the calculated values thereof suggest a possibility of only low to moderate surface chemical activity. For example, a highly active Na^{++} montmorillonite might show an AI value in excess of 3. Assuming low to moderate activities of the region's finer particulates, the analysis thus suggests chemical products with high surfactant or flocculant properties might produce little or no effective dust control measures. Though the first two groupings of particle sizes suggest considerable potential for large quantities of wind transportable fine sands, silts and clays, selection of dust control products might therefore have to be limited to binders and/or matrix enmeshing types of agents.

Permeability values presented in Table 1 suggest soil materials of the region of low to medium gravitational flow. A few exceptions may be noted as either potentially high permeability, or in the case of hardpan subsoils, of very low permeability. In general, one might classify the bulk of the region's subsoils to be of somewhat moderate permeability. From the standpoint of dust palliatives applied as sprays in aqueous solution or dispersion forms, the general permeabilities suggest possible penetration, particularly to quiescent areas where the soils have not been consolidated or densified under traffic. Similar application techniques might also be justified where densification has occurred, but only for those limited soils showing more of a uniform particle size distribution, such as the SP or SM types of classification.

While the region's soils have been derived from both acidic and alkaline rock formations, factors influencing the development of soil profiles of the region have produced generally alkaline conditions. This is noted in the estimated range of pH values, Table 1. With pH = 7.0 being neutral, the lowest estimated pH of the region's soils is 7.9, the highest 9.6; moderate to high alkalinity. A number of the regional soils were noted to contain anywhere from "filament," to "soft masses," to "strong" concentrations of lime, with a few individual lime hardpans and lime cemented hardpans [2,3]. It must be assumed therefore that dust control products which may be adversely affected by alkaline soil conditions would produce none to only short term beneficial effectiveness if applied within the Phoenix metropolitan region.

Shrink-swell potential, Table 1, predominantly relates to the expansion or contraction characteristics of the finer clay and colloidal size fractions of a soil depending on the availability of soil water. Such characteristics also relate to mineralogy of these weathered fine fractions, which in turn are related to size and charge of interlayered ions; i.e., surface chemical activity as often measured through the cation exchange capacity test. For example, montmorillonite undergoes cycles of expansion and shrinkage depending on water availability, whereas kaolinitic clays do not. Intermediate between the montmorillonites and kaolinites are illitic clay minerals which range from less readily expandable, to non-expandable. Many common non-clay minerals such as quartz and feldspars are non-expandable but, however, may be somewhat prone to bulking in the presence of water. Bulking is a condition more closely related to capillary and hygroscopic films of moisture that tend to create volumetric increases through opening of the soil skeletal structure, subsequently disappearing if more water is added.

Shrink-swell ratings noted in Table 1 are predominantly low to moderate. Such ratings do not specifically define the mineralogical types of fines of the Phoenix region, nor whether such ratings are related to bulking rather than potential exchange characteristics. However, the ratings suggest that either condition is of only low to moderate occurrence. If such occurrence is due to possible exchange phenomena, chemical dust control products containing low to moderate amounts of exchangeable ions may produce flocculation/aggregation effects of the fine particulates. If such occurrence is due to bulking, chemical dust control products which provide greater capillary tensile forces than water only, may produce effective flocculation/aggregation.

In summary, soils of the Phoenix metropolitan region appear viable for use with a wide range of dust control products. Exceptions to this statement may be:

(1) Products containing large quantities of surfactants, i.e., products which are exclusively dependent on exchange reactions,

(2) Products which may be incompatible with carbonates, or

(3) Hygroscopic/deliquescent products, due to low humidity of the region and not necessarily related to various properties of the soils.

LITERATURE REVIEW OF DUST CONTROL AGENTS AND PROCESSES

Control of dust from construction sites may be viewed as (1) wind generated from relatively quiescent areas where construction activities are infrequent, and (2) a combination of construction activity plus wind, such as may occur with continuous vehicle or equipment movement. Except for periods of high or gusty winds, quiescent areas may require only limited amounts of preventive control. In predominant areas of construction operations, control must be viewed as (1) either a continuous activity or (2) as a periodic activity involving placement of palliative agents.

Regardless of its generated source, dust creates problems and issues involving user costs, environmental quality, public irritation, higher maintenance costs of vehicles and equipment, and safety and health hazards [1,5,9,13]. Increased public awareness of pollution, conservation of natural resources, and increased user costs, have spawned a generation with interest in, and development of, methods and products for control of dust. However, as early as 1909, when the "Office of Public Roads" suggested clay-bound stone as the surfacing for roads in order to alleviate dusting and raveling [12], engineers have attempted to provide the public with possible dust control measures. Short term relief from dust has tended to occur through trial and error technology by use of a variety of products and additives, such as chlorides, asphaltic compounds, oils, and lignins. Most often however, such trial and error approaches have been limited in scope and success, and where available and affordable, reversion has occurred to watering, particularly in construction zones.

Water is but a temporary measure of relief. Frequency of water application in a construction zone depends heavily on climate and weather, more specifically on humidity and wind. In general, repeated light applications of water are usually better than a single heavy application, since the latter most often turns dust particulates to mud, tends to destroy capillary flocculability of fine particulates, and may even wash away clay/colloidal size particles that provide essential bonding of silt or sand size particles. Continuous watering may thus increase susceptibility of a soil to dust production.

Dust originates from instability of the surficial zone of a soil profile that may be attacked by the mechanical forces of wind, water, or vehicles. It is therefore the purpose of any dust control measure or product, to provide the necessary stabilization qualities to resist such mechanical forces. Normally, stabilization will be required only within the upper few inches of the profile, thickness being dependent on soil characteristics, density, penetrability, wind, humidity, rainfall, and vehicular abrasion and loadings.

In order to prevent particles from becoming airborne, the stabilization product must cause flocculation of the particulates either to one another or to larger size particles, i.e., aggregate formation, or be enveloped in a tightly formed matrix. Either stabilization format may be accomplished through surface penetration applications, or through mixed-in-place techniques. Surface applications are generally more closely associated with unstable quiescent areas where a product may be able to penetrate 0.5-1.0 inch, due to the degree of disturbance of the upper portion of the profile. Surface applications are of little value when applied on dense, traffic-bound soils, due to their inability to penetrate, and a consequent lack of flocculated or aggregation development. Mixed-in-place techniques are more closely associated with trafficked areas, where a product can be intimately mixed into the upper 2-4 inches and compacted. Mixed-in-place techniques generally provide longer term effectiveness of dust control [9] through better particle envelopment by a stabilization product, and greater resistance to traffic abrasion.

For ease of application by either surficial or mixed-in-place techniques, an economically useful dust control product is preferably compatible with water. Other forms of product carriers or cutters have generally been of a hydrocarbon variety, but must be frowned on due to their evaporability, causing increased hydrocarbons in the atmosphere. For effectiveness, the preferred water-borne product must provide increased capillary forces in the soil, cause electrostatic compatibilities between particles, or provide matrix encapsulation of particles as the water carrier evaporates. Product residue remaining after water evaporation must continue to provide the preceding requirements, as well as resist aging, not leach out or soften during rainfall, and not be evaporable by itself.

Dust control agents have been classified into a number of varying categories. For example, penetrants versus mixed-in-place, or petroleum versus non-petroleum products. However, such categorization is somewhat irrelevant, since some products can be utilized as both palliative/penetrants, or mixed-in-place, and many chemical agents are by-products of the petroleum industry yet may not contain hydrocarbons due to their present chemical format. Such classifications therefore, do not tend to relate to the manner in which a product may or may not provide dust control effectiveness.

In this report, it is suggested that nomenclature of dust control agents be examined on the basis of their known, presumed, or hypothesized mechanisms of soil stabilization and will include three broad formats:

- First, those products which modify surface tension of the capillary moisture regime in a soil, hereafter referred to as capillary modifiers.
- Second, those products which act as binders of particulates due to (1) adhesive properties attained through glue-like characteristics of the base product, or (2) which have been chemically modified to provide electrostatic or exchangeable ionic properties for flocculative purposes.
- Third, those products which may provide macromolecules of a chain or rootlike envelopment matrix due to their polymeric or elastomeric properties, hereafter referred to as P/E additives.

Literature reviews presented in Tables 2 and 3, plus supplementary product reviews contained in subsequent areas of the text herein, have been selected as a broad representation of products, their usage, application rates, costs, and effectiveness, as might be considered for dust control on construction sites in the Phoenix metropolitan area. Some products have purposely been left out due to a lack of satisfactory literature available. Some authors and literature have also been excluded from this report, not due to ineptness or lack of knowledge with such literature, but due only to the desire to refrain from considerable duplication and repetition.

Table 2 is a selective summation of both field and laboratory chemical stabilizers reported to a Transportation Research Board (TRB) questionnaire by various transportation agencies [14]. This table is oriented to those products used primarily for dust and erosion control. Products reported in Table 2 may be noted as ranging in effectiveness from good to poor, having generally been applied as both spray and mixed-in-place forms of application. Application rates were extremely variable, not necessarily reported as actual rates per area, but occasionally as the dispersion rate in water. Costs noted in Table 2 are those reported in the TRB publication and are associated with the early or mid-1970's. Assuming the products still to be available, costs would more than likely be at least doubled today.

Products of Table 2 generally can be placed in the broad mechanistic nomenclature previously noted. Chlorides, SA-1, Paczyme, Chempact (Chem-Pak), Aquatain, Wellpack, Reynolds Road Packer, various protein colloids, corn extracts, starch, and cellulose, generally fit mechanistically into capillary modifiers. Several of these products tend to remove organic matter, neutralize alkaline soil conditions, or attack carbonates, due to their acidic nature. Most of these products will tend to reduce the capillary moisture tension regime in a soil, often increasing density, or providing an ease of densification of a soil. However, several of these products have often been shown to

Table 2. Selected Summary of Field and Laboratory Chemical Stabilization by Various Transportation Agencies as Reported to the Transportation Research Board, 1977 [14].

Product	Soil Type	Purpose of Treatment	Cost	Application Rate	Application Method	Effectiveness
Lignin	Crushed gravel	Dust control	$650/mile/lane	1-5%	Spray	Temporary
Lignin	Sand/Sandy loam	Strength gain	$0.37/sq. yd.	4% by volume	Mixed--4 in.	Strength gain
Soils Organic Binder (Lignin)	Silty Clay A-6 (14)	Increase stability	Not given	1:4 by volume in water	Mixed	Poor
Lignin	Silty/Sandy Gravel	Decrease frost action/dust control	$26,770.30/2.5 miles	1:1 by volume in water	Not given	Fair
Lignin	A-6(1), PI = 13	Stability/dust control	Not given	1-4%	Not given	Dust control-good Stability-poor
Lignin	A-5 and uniform gravel	Stabilization	$6000/mile	1 gal/sq.yd., 6 in.	Mixed	Good
Soils Organic Binder (Lignin)	A-2-4, LL = 30, PI = 9, pH = 7.5	Working platform for RC treatment	$3500/mile	10,000 gal/mile	Not given	Fair
Sulfite Liquor (Lignin)	Silty Gravel, 10% pass #200	Stabilization	Not given	Not given	Mixed	Poor
Lignite (Lignin)	Pierre Shale	Decrease swelling	Not given	5%	Not given	Poor
Sodium Chloride	Sand/Clay/Gravel mix	Stabilization	Not given	1.25 and 2.5% by wt.	Mixed	For same cost, lime was superior
Calcium Chloride	Glacial clay	Stabilization and dust control	Not given	1.5 lb/sq. yd.	Mixed	Good-but did not control dust in dry weather
Terbec C-7	Clay loam/Silty clay loam	Waterproofing soil	$0.77/sq. yd.	0.12% by wt.	Mixed	Effective
Arquad 2HT (quaternary ammonium chloride)	A-4 to A-6	Strength and waterproofing	Not given	0.13-0.19% by wt.	Mixed	Poor
SA-1 (Acid)	A-2-4, LL = 30, PI = 9, pH = 7.5	Working platform for RC seal treatment using ¼ in. sand	$750/mile, including water, compaction, and shaping.	28 gal/mile	Spray	Poor

Table 2. Selected Summary of Field and Laboratory Chemical Stabilization by Various Transportation Agencies as Reported to the Transportation Research Board, 1977 [14] (CONTINUED)

Product	Soil Type	Purpose of Treatment	Cost	Application Rate	Application Method	Effectiveness
SA-1 (Acid)	Sand and Clay	Increase density, stability, and improve moisture characteristics	Not given	1/1000 (water by volume)	Blended, bladed, compacted	Poor
Paczyme (Enzyme)	Silty and Clayey soil	Stabilize surface and subgrade	Not given	5/100 (water by volume)	Spray	Poor
Resin in water emulsion	Not given	Stabilize soil surface for wind and water erosion	$225 for sandy loam $415 for silty clay loam	600 gal/acre, sandy loam 1200 gal/acre, silty clay loam	Not given	Effective on sandy and medium textured soils, not on clays and silty clays
Ammonium ligno-sulfonate; gelatin-ized starch solution; sodium silicate solution	Not given	Wind and water erosion	Not given	Not given	Not given	Poor
Chempact (Chem-Pak)	Clay and sand	Determine suitability as soil stabilizing agent	$25/gal.	1/1000 (water by volume)	Mixed	Poor
Aquatain, water-soluble chemicals, and pectin	A-7-5, LL = 70, PI = 20	Erosion control	$3.2/gal.	3 gal. of stabilizer to 16.5 gal. of water per 1000 sq. ft.	Spray	Poor
Aerospray 70 (poly-vinyl acetate resin emulsion)	Weathered rock	Erosion control	$0.404/sq. yd., diluted 1:10	2 gal/sq. yd.	Spray	Temporary control
Peneprime (liquid asphalt)	A-2-4	Working platform	$3300/mile	14,000 gal/mile	Not given	Temporary to poor
Formaldehyde and polyester resin	A-5(3)	Develop slab strength	$1.71/ft.	20 to 40% by wt.	Mixed and compacted	Good
Latex in water emulsion	Not given	Wind and water erosion	$1.6/gal.	1200 gal/mile	Not given	Satisfactory

Table 2. Selected Summary of Field and Laboratory Chemical Stabilization by Various Transportation Agencies as Reported to the Transportation Research Board, 1977 [14] (CONTINUED)

Product	Soil Type	Purpose of Treatment	Cost	Application Rate	Application Method	Effectiveness
Wellpack (organic)	Silty gravel	Stabilizing subgrade	Not given	1:750 (water)	Spray and mixed	Poor
Styrene-butadiene emulsion (resin)	89.6% sand, 5.9% silt, 4.5% clay	Wind erosion	Not given	205 gal/acre	Not given	Poor
Styrene-butadiene emulsion (resin)	Shale	Prevent shale road cuts from weathering	Not given	Not given	Not given	Poor
Reynolds Road Packer (Acid)	LL = 56, PI = 44	Reduce plasticity, increase stability, reduce dusting	$0.28/sq. yd.	1:1000 by volume	Mixed	Poor
SBR Latex S-2105 (Styrene-butadiene latex resin)	89.6% Sand, 5.9% silt, 4.5% clay	Wind erosion	$27.40/acre	226 gal/acre (diluted 1:12.5 with water)	Spray	Good
Polyco 2460 (Latex resin)	Same as above	Wind erosion	$26.90/acre	184 gal/acre (diluted 1:10 with water)	Spray	Good
Petroset SB (Resin-water emulsion)	Same as above	Wind erosion	$49.50/acre	433 gal/acre (diluted 1:19 with water)	Spray	Good
Polyco 2605 (Latex resin)	Same as above	Wind erosion	$40.80/acre	351 gal/acre (diluted 1:20 with water)	Spray	Good
DCA-70 (Polyvinyl acetate water emulsion)	Same as above	Wind erosion	$36.50/acre	226 gal/acre (diluted 1:12.5 with water)	Spray	Good
Technical Protein Colloid 2260 (Liquid protein colloid 13-14%N)	Same as above	Wind erosion	$46.00/acre	216 gal/acre (diluted 1:10 with water)	Spray	Fair to poor
Technical Protein Colloid 2236 (Liquid protein colloid 13-14%N)	Same as above	Wind erosion	$103.20/acre	466 gal/acre (diluted 1:10 with water)	Spray	Fair to poor
Technical Protein Colloid 5-V (Granular protein colloid 15-16%N)	Same as above	Wind erosion	$34.60/acre	128 gal/acre (diluted 1:10 with water)	Spray	Fair to poor

Table 2. Selected Summary of Field and Laboratory Chemical Stabilization by Various Transportation Agencies as Reported to the Transportation Research Board, 1977 [14] (CONTINUED)

Product	Soil Type	Purpose of Treatment	Cost	Application Rate	Application Method	Effectiveness
Technical Protein Colloid 1-V (Granular protein colloid 15-16%N)	89.6% sand, 5.9% silt, 4.5% clay	Wind erosion	$31.30/acre	128 gal/acre (diluted 1:10 with water)	Spray	Fair to poor
Goodrite 2570 X1 (Styrene Butadiene Latex)	Same as above	Wind erosion	$25.40/acre	184 gal/acre (diluted 1:10 with water)	Spray	Fair to poor
Gantrez An-119 (Liquid Monoester Resin)	Same as above	Wind erosion	$43.60/acre	260 gal/acre (diluted 1:57 with water)	Spray	Fair to poor
Geon 652 (Liquid Vinyl-Chloride-Vinyl idene chloride Latex)	Same as above	Wind erosion	$51.20/acre	351 gal/acre (diluted 1:20 with water)	Spray	Fair to poor
E-802 Mazofern Brand Fermented Corn Extractives	Same as above	Wind erosion	$22.00/acre	563 gal/acre (diluted 1:10 with water)	Spray	Fair to poor
Aerospray 52 Binder (Synthetic resin in water emulsion)	Same as above	Wind erosion	$29.90/acre	661 gal/acre (diluted 1:15 with water)	Spray	Fair to poor
Styrene-Butadiene Emulsion	Same as above	Wind erosion	Not given	205 gal/acre (diluted 1:3 with water)	Spray	Fair to poor
CMC-7-L, CMC-7-M. (Sodium carboxy methyl cellulose, L = Low viscosity, M = Medium viscosity)	Same as above	Wind erosion	$28.40/acre	431 gal/acre (diluted 1:84 with water)	Spray	Fair to poor
Curasol AE (Polyvinyl acetate copolymer-emulsion)	Same as above	Wind erosion	$89.70/acre	571 gal/acre (diluted 1:12.5 with water)	Spray	Fair to poor
Elvanol 50-42 (Polyvinyl alcohol)	Same as above	Wind erosion	$8.20/acre	123 gal/acre (diluted 1:80 with water)	Spray	Fair to poor
Elvanol 71-30 (Polyvinyl alcohol)	Same as above	Wind erosion	$6.90/acre	42 gal/acre (diluted 1:27 with water)	Spray	Fair to poor

Table 2. Selected Summary of Field and Laboratory Chemical Stabilization by Various Transportation Agencies as Reported to the Transportation Research Board, 1977 [14] (CONTINUED)

Product	Soil Type	Purpose of Treatment	Cost	Application Rate	Application Method	Effectiveness
Gantrez ES-335I (Liquid Monoester Resin)	89.6% sand, 5.9% silt, 4.5% clay	Wind erosion	$103.10/acre	351 gal/acre (diluted 1:20 with water)	Spray	Fair to poor
Gypsum Hemihydrate (Powder gypsum)	Same as above	Wind erosion	$16.60/acre	3064 gal/acre (diluted 1:20 with water)	Spray	Fair to poor
NC 1556L (Modified polyacrylamide)	Same as above	Wind erosion	$59.49/acre	535 gal/acre (diluted 1:31 with water)	Spray	Fair to poor
Separan Np-10 polyacrylamide, high molecular weight	Same as above	Wind erosion	$25.20/acre	6173 gal/acre (diluted 1:4375 with water)	Spray	Fair to poor
Soil Erosion Control Resin Adhesive Z-3876	Same as above	Wind erosion	$1,159.90/acre	1712 gal/acre (diluted 1:2 with water)	Spray	Fair to poor
Soilguard (Elastomeric polymer)	Same as above	Wind erosion	$32.20/acre	455 gal/acre (diluted 1:10 with water)	Spray	Fair to poor
Soil Seal (Formulation of polymers and latex)	Same as above	Wind erosion	$149.60/acre	366 gal/acre (diluted 1:9 with water)	Spray	Fair to good
Wicaloid Latex ex 7035 (AD) (Carboxylated styrene-butadiene latex)	Same as above	Wind erosion	$14.40/acre	226 gal/acre (diluted 1:12.5 with water)	Spray	Fair to poor

reduce stability of a soil, since their effect on the capillary regime may actually provide dispersion of naturally aggregated particulates [15]. As noted in Table 2, the reported effectiveness of these products was generally poor, a few rated fair to poor.

Lignosulfonates, Terbec C-7, Arquad 2HT, sodium silicate, and Peneprime, Table 2, are generally binder materials. When slightly moist, soil/colloidal lignosulfonate composites are very sticky; when dry, they form surficial crusty patinas of the lignosulfonate, which may become slick when rewetted. Terbec C-7 and Arquad 2HT were soil modifiers, producing binding or flocculative capabilities primarily through exchange reactions with a soil. Sodium silicate should produce a gel-like stabilizer if mixed with calcium chloride in certain soils. However, both the lignin and silicate are noted in Table 2 as having produced poor wind and water erosion results. Peneprime was a commercial, specially processed, cutback asphalt thought to also contain a resin. It was originally formulated as an asphalt rejuvenator. As noted in Table 2, it provided only temporary to poor effectiveness with an A-2-4 soil, and at a high cost. Recommendations by Hoover, et al. [16] for use of Peneprime as a dust palliative/surface improvement product for an A-1-b soil also indicated only limited potential.

The remainder of the products of Table 2 include various resinous emulsions, latex products, emulsified plastics, polymers, and combinations of several of the aforementioned. Of these products, several are noted as producing good effectiveness. A combination of formaldehyde and polyester resin was used to develop slab strength in an unusual A-5 soil, at a very high application rate and cost. In a sandy material of only about 10% fines content, SBR Latex S-2105, Polyco 2460, Petroset SB, Polyco 2605, DCA-70, and Soil Seal, produced good effectiveness for wind erosion control at very low costs. Mechanistically, each of these six products would be referred to as P/E additives. Four of the products are primarily latex-based water emulsions, though Soil Seal may contain a polymer. The two remaining products are a polyvinyl acetate water emulsion, and the Petroset SB, a cationic latex emulsion. Petroset SB also was evaluated by Hoover, et al. [16] and recommended for trial as a dust palliative/surface improvement agent. Soil Seal, noted by the producer as a water soluble plastic emulsion, indicated potential viability when laboratory evaluated as a dust palliative with an SM-SC soil in 1985 [25].

Of the products presented in the TRB summary compilation of Table 2, only those showing mechanistic P/E properties appeared to produce adequate effectiveness at a reasonable cost, each being used for wind erosion control, and each being spray applied in a water diluted form. None of the Table 2 products were reported in terms of actual longevity; a not uncommon process of follow-up analyses by most agencies. However, it must be assumed that where a product effectiveness was rated good, that longevity was apparent over whatever period of effectiveness was sought.

Table 3 is a selected summary of field stabilization by a number of agencies and investigators using various chemical products. Presented is an extremely diverse range of both soil types and products, including somewhat more recent developments in stabilization, dust, and water erosion control products than reviewed in Table 2. Project literature incorporated in Table 3 also includes somewhat more information on relative costs of products at time of reporting, frequence of application, and tendencies of

Table 3. Selected Summary of Field Stabilization by Various Investigators.

Location	Product	Soil Type	Purpose of Treatment	Application Rate	Cost	Application Method	Frequency of Application	Effectiveness	Biblio. Ref. No.
Linn County, Iowa	Lignosulfonate and Lignosulfonate + alum	A-2-4	Stabilization, dust control	1% by wt. lignin; 0.5% by wt. alum	Lignin, $3350/mile; alum, $250/mile	Mixed, 4 inches	Once	Good over 1 year	16
Not given	Sulphite liquor (lignosulfonate)	Silt/clay	Dust control	0.5 gal/sq. yd.	$900/mile	Spray	1-2/year	Good, though destroyed by rain	18
Taylor County, Iowa	Bindtite (lignosulfonate)	Not given	Stabilization, dust control	1% by wt.	$6600/mile for 6 inch depth	Mixed	Not given	Good	17
Arizona	Lignosulfonate	Dune sand	Wind erosion, dust control	Not given	Not given	Spray	Not given	Good	20
Arizona	Lignosulfonate	Gravel-surfaced granitic subgrade	Dust control	Not given	Not given	Mixed-in-depth	Not given	Good	20
Franklin County, Iowa	Ammonium lignosulfonate	A-2-4	Dust control	0.23 gal/sq. yd. at 2.25:1 dilution	$2440/mile	Spray	Once	Good to fair after 3 months	5
Franklin County, Iowa	Polybind Acrylic DLR 81-03	A-2-4	Dust control	0.17 gal/sq. yd. (twice) at 40:1 dilution	$1550/mile	Spray	Once	Fair after 3 months	5
Franklin County, Iowa	Amsco Res AB 1881 over old ammonium lignosulfonate	A-2-4	Dust control	0.12 gal/sq. yd. at 17:1 dilution	≈$700/mile	Spray	Once	Good after 4 months	5
Franklin County, Iowa	Amsco Res AB 1881	A-2-4	Dust control	0.12 gal/sq. yd. at 17:1 dilution	≈$700/mile	Spray	Once	Poor after 2 weeks	5
Linn County, Iowa	Lignosulfonate	Very sandy soil	Stabilization, dust control	1.5% by wt.	Not given	Mixed	Once	Good; after 2 months received 4 in. A.C. surface	25
Linn County, Iowa	Liquidow, 35% calcium chloride solution	A-2-6	Stabilization, dust control	1/3 gal/sq. yd., 6 in. deep	Not given	Mixed	Once	Good, received seal coat surface	21

Table 3. Selected Summary of Field Stabilization by Various Investigators. (CONTINUED)

Location	Product	Soil Type	Purpose of Treatment	Application Rate	Cost	Application Method	Frequency of Application	Effectiveness	Biblio. Ref. No.
Not given	Sodium, calcium, magnesium chlorides	Silt/clay	Dust control	0.5 to 2.5 lbs/ sq.yd.	$2500/yr. over 10 yrs.	Spray	Twice annually	Good, though destroyed by rain	18
Linn County, Iowa	Sodium chloride	A-3	Stabilization, dust control	12 lbs/sq.yd., 6 in. deep	Not given	Mixed	Once	Good, received seal coat surface	21
Franklin County, Iowa	Calcium chloride, 38% solution	A-2-4	Dust control	0.18 gal/sq.yd.	$1120/mile	Spray	Once	Good after 4 months	5
Franklin County, Iowa	Calcium chloride over old ammonium lignosulfonate	A-2-4	Dust control	0.18 gal/sq.yd.	$1120/mile	Spray	Once	Good after 4 months	5
Franklin County, Iowa	CSS-1 asphalt emulsion	A-2-4	Dust control	9:1 @ 0.2 gal/ sq.yd., then 5:1 @ 0.2 gal/ sq.yd.	$850/mile	Spray	Once	Dust < 60 days, Poor @ 4 months	5
Franklin County, Iowa	Coherex	A-2-4	Dust control	6:1 @ 0.37 gal/ sq.yd., then 4:1 @ 0.29 gal/ sq. yd.	$5230/mile	Spray	Once	Dust free @ 4 months; Spalling < 60 days	5
Franklin County, Iowa	Coherex over old ammonium lignosulfonate	A-2-4	Dust control	Same	Same	Spray	Once	Dust free @ 4 months, no spalling	5
Story County, Iowa	Coherex	A-6(4)	Dust control	0.5% by wt.	Product: $3775/mile; Manipulation: $4240/mile	Mixed, 2 inch	Once	Good after 8 months	5
Marion County, Iowa	Coherex	A-2-4 w/ absorptive stone	Dust control	0.2% by wt. & 0.7% by wt., assumed 1 in. penetration	$1100/mile; $4940/mile	Spray-equal parts at 1 week	Once	Poor < 1 month	5
Linn County, Iowa	Lignosulfonate	A-2-4	Stabilization, dust control	1.5 gal/sq.yd.	Not given	Mixed, 6 inch	Once	Good, eventually given seal coat surface	21

Table 3. Selected Summary of Field Stabilization by Various Investigators. (CONTINUED)

Location	Product	Soil Type	Purpose of Treatment	Application Rate	Cost	Application Method	Frequency of Application	Effectiveness	Biblio. Ref. No.
Linn County, Iowa	Lignosulfonate + lime	A-7-6(12)	Stabilization, dust control	1 gal/sq.yd. and 2% by wt. lime	Not given	Mixed, 6 inch	Once	Good, eventually given seal coat surface	21
Linn County, Iowa	Lignosulfonate + Pramitol C25	A-2-4	Stabilization, dust control	1.5 gal/sq. yd. and 20 gal/acre	Not given	Mixed, 6 inch	Once	Good, eventually used as A.C. subbase	21
Linn County, Iowa	Kelpak	A-2-4	Stabilization, dust control	10 gal/1000 gal of water	Not given	Mixed, 6 inch	Once	Poor	21
Linn County, Iowa	Clapak/ Claset	A-6	Stabilization, dust control	15 gal. Clapak, 10 gal. Claset in 3000 gal. water	Not given	Mixed, 6 inch	Once	Fair	21
Linn County, Iowa	SA-1	A-4	Stabilization, dust control	1 gal/1000 gal of water	Not given	Mixed, 6 inch	Once	Fair	21
Linn County, Iowa	CSS-1 asphalt emulsion	A-2-6	Stabilization, dust control	4% residual by weight	Not given	Mixed, 6 inch	Once	Good, seal coat surfaced after 3 months	21
Linn County, Iowa	CSS-1 asphalt emulsion	A-6(2)	Stabilization, dust control	4% residual by weight	Not given	Mixed, 6 inch	Once	Good, seal coat surfaced after 3 months	21
Linn County, Iowa	Terra-Seal (enzyme)	A-6(1)	Stabilization, dust control	1 gal/1000 gal of water	Not given	Mixed, 6 inch	Once	Poor	21
Iowa	Oil	Not given	Dust control	0.25 gal/sq.yd.	≅$0.03/sq.yd.	Spray	Not given	Fair	25
Des Moines, Iowa	CSS-1 emulsified asphalt	Sandy clay	Dust control	0.1-0.25 gal/ sq.yd.	Not given	Spray	Not given	Good	25
Not given	Tars and bitumens	Silt/clay	Dust control	Not given	High	Spray	Not given	Short-lived	18
New Mexico	Petro-S (sodium alkyl ethylene sulfonate)	Highly calcitic SC soil	Stabilization, dust control	0.1% by wt., 6 inches deep	Not given	Mixed	Once	Good, after 2.5 months	15

Table 3. Selected Summary of Field Stabilization by Various Investigators. (CONTINUED)

Location	Product	Soil Type	Purpose of Treatment	Application Rate	Cost	Application Method	Frequency of Application	Effectiveness	Biblio. Ref. No.
Arizona	Terrakrete No. 2 (vinyl acetate acrylic copolymer)	96% pass No. 4; 60% pass No. 200	Untrafficked dust control	0.5 gal/sq. yd. at ≈ 6% solution	$0.06/sq.yd.	Spray	Once	Good after 15 months	19,20
Arizona	Surfaseal, 1:10	Same	Same	1/3 gal/sq. yd., 1:10 dilution	$0.13/sq.yd.	Spray	Once	Same	19,20
Arizona	Dust control oil (petroleum resin and solvent)	Same	Same	0.25 gal/ sq.yd.	$0.11/sq.yd.	Spray	Once	Same	19.20
Arizona	Norlig 41 + F125 (lignosulfonate + chemicals)	Same	Same	1 gal/sq.yd. at 1:4 dilution	$0.09/sq.yd.	Spray	Once	Same	19,20
Arizona	Coherex (petroleum resins and wetting solution)	Same	Same	1 gal/sq.yd. at 1:7 dilution	$0.06/sq.yd.	Spray	Once	Same	19,20
Arizona	Dust control oil	99% pass No. 4; 28% pass No. 200	Road dust control	0.5 gal/sq.yd.	$0.22/sq.yd.	Spray	Once	Good after 12 months	19,20
Arizona	Dust Bond 100 + F125 (lignosulfonate + chemicals)	Same	Same	1 gal/sq.yd.	$0.41/sq.yd.	Spray	Once	Good for 5 months	19,20
Arizona	Aerospray 70 (polyvinyl acetate resins)	Same	Same	1 gal/sq.yd. at 1:6 dilution	$0.40/sq.yd.	Spray	Once	Same	19,20
Arizona	Curasol AE (polymer dispersion)	Same	Same	1 gal/sq.yd. at 1:6 dilution	$0.40/sq.yd.	Spray	Once	Same	19,20
Arizona	Foramine 99-194 (urea-formaldehyde resin)	Same	Same	1 gal/sq.yd. at ≈ 1:2 dilution	$0.51/sq.yd.	Spray	Once	Same	19,20

Table 3. Selected Summary of Field Stabilization by Various Investigators. (CONTINUED)

Location	Product	Soil Type	Purpose of Treatment	Application Rate	Cost	Application Method	Frequency of Application	Effectiveness	Biblio. Ref. No.
Arizona	Redicote E-52 (CSS-1 asphalt emulsion)	99% pass No. 4; 28% pass No. 200	Road dust control	7.4% emulsion by wt. @ 2.4 gal/sq.yd.	$0.53/sq.yd.	Mixed, 3 inch	Once	Good after 15 months	19,20
Arizona	Dust Bond 100 + F125	Same	Same	1 gal/sq.yd.	$0.41/sq.yd.	Mixed, 3 inch	Once	Good for 5 months	19,20
Arizona	Dust control oil	Same	Same	0.5 gal/sq.yd.	$0.22/sq.yd.	Mixed, 3 inch	Once	Same	19,20
Saskatchewan, Canada	Calcium chloride brine	SM-SC	Dust control	First: 10 tons/mile; Second: 4 tons/mile	$1308/mile	Spray	Twice	Good through one season	22
Saskatchewan, Canada	Calcium chloride brine + pelletized sodium chloride	SC	Same	10 tons/mile NaCl, 6 tons/mile $CaCl_2$	$ 904/mile	Dry plus spray	Once	Fair to poor	22
Saskatchewan, Canada	Bulk sodium chloride	SC	Same	30 tons/mile	$ 869/mile	Dry	Once	Poor	22
Saskatchewan, Canada	Bulk sodium chloride	SC-SM	Same	15 tons/mile	$ 494/mile	Dry	Once	Poor	22
Saskatchewan, Canada	Bulk sodium chloride	ML	Same	15 tons/mile	$ 388/mile	Dry	Once	Poor	22
Saskatchewan, Canada	Asphalt emulsion	SM-SC	Same	First: 0.25 gal/sq.yd. Second: 0.17 gal/sq.yd.	$1829/mile	Spray	Twice	Fair	22
Saskatchewan, Canada	Calcium lignosulfonate	SC to CL	Same	0.4 gal/sq.yd.	$1366/mile	Spray	Once	Fair to good	22
South Dakota/ Nebraska	Liquid cutback asphalt	Dune sand	Wind erosion	1 gal/sq.yd. each application	Not given	Spray	Twice	Good > 5 years	23
Utah	Polyvinyl acetate emulsion	Not given	Slope erosion	3 gal/sq.yd. at 1:9 dilution	$1.59/sq.yd.	Spray and mix, per 2 inch thick	Once	Fair after 2 years	23

Table 3. Selected Summary of Field Stabilization by Various Investigators (CONTINUED)

Location	Product	Soil Type	Purpose of Treatment	Application Rate	Cost	Application Method	Frequency of Application	Effectiveness	Biblio. Ref. No.
California	Polyvinyl acetate emulsion	Not given	Slope erosion, dust control	1 gal/sq.yd. at 1:9 dilution	$0.41/sq.yd.	Spray	Once	Good > 2 years	23
California	Liquid cutback asphalt	Not given	Haul road dust control	Not given	$0.56/sq.yd.	Not given	Not given	Not given	23
North Dakota	Urethane liquid	Gravel	Water erosion	Not given	Not given	Spray	Once	Good > 4 months	23
Tehama-Colusa Canal	Copolymer of methacrylates and acrylates	Not given	Spoil bank erosion control	0.64 gal/sq. yd. at 1:37 dilution	Not given	Spray	Once	Good > 3 years	23
Putah South Canal	Polyvinyl acetate emulsion	CL	Erosion control prior to vegetative cover	1.3 gal/sq. yd. at 1:19 dilution	$0.11/sq.yd.	Spray	Once	Good < 1 year	23
Tehama-Colusa Canal	Latex emulsion	Not given	Erosion control prior to vegetative cover	1.6 gal/sq. yd. at 1:7 dilution	Not given	Spray	Once	Good > 6 months	23
Tehama-Colusa Canal	Copolymer of methacrylates and acrylates	CL-SM	Road dust control, stabilization	1:30 dilution of 660 gal/ 526 cu.yds.	$2357, including equip. and labor	Mixed, 4-6 inches	Once	Good after 2 months	23
Nevada-California	Urethane liquid	CL-CH	Erosion control	0.3 to 0.45 gal/sq.yd.	Not given	Mixed < 0.5 inch	Once	Good after 6 months	23
Colorado	Petroleum resin emulsion	Mine tailings	Dust control from tailings pond	0.5 to 1.0 gal/sq.yd. at 1:9 dilution	$0.42/gal and $100/ acre	Spray	As needed	Good	23
Arizona	Corexit 178 (polymer)	Sand	Road and quiescent dust control	< 0.15 gal/sq. yd. at 1:9 dilution	Not given	Mixed and spray	Once	Good after 5 months	24
Iowa	Corexit 178	A-3	Road dust control	0.1% by wt.	Not given	Mixed, 3 inches	Once	Good after 4 months	8
Story County, Iowa	Sunflower oil	Cinders, bottom ash	Dust control	≈0.2 gal/sq. yd.	Not given	Mixed, 2 inches	Once	Good after 7 months	25

longevity of product performance.

Capillary Modifiers

Stabilization mechanisms of products presented in Table 3 may again be viewed as previously noted. Capillary modifiers Liquidow, various other sodium, calcium and magnesium chlorides, SA-1, Kelpak, Clapak/Claset, and Terra-Seal, may be noted throughout Table 3 as having produced good to poor results. Of these products, only the chlorides appeared to provide good effectiveness, the calcium chloride appearing somewhat better than either sodium or magnesium.

Two items of importance should be observed with chloride effectiveness. First, the product should be mixed with the soil, in order to provide longevity against rain. Second, where spray applied, climatic conditions must usually lend themselves to a reasonable quantity of humidity. Humidity is particularly important in the use of sodium chloride, for example, since it may require 70% or greater relative humidity in order to maintain its hygroscopic properties; otherwise, it tends to precipitate and is not effective in that mode.

In a recent study for the Roads and Transportation Association of Canada [27], chlorides were assessed for their effectiveness as dust palliatives. In general, chlorides were rated as fair, but effectiveness ratings were somewhat dependent on soil types, or the Province in which such products were used.

In response to a 1985 questionnaire from the Transportation Research Board, the Alaska Department of Transportation and Public Facilities reported the use of calcium chloride as an adequate dust palliative over the previous ten years [28].

A laboratory evaluation of sodium chloride mixed with a relatively well graded soil indicated a potential for increased density, increased moisture retention, and improved trafficability test performance, but decreased cohesion and increased the soil's angle of internal friction and pore pressure [33]. Field evaluation of a 6 inch mixed-in-place NaCl stabilized A-3 sand with a double chip seal surface has produced a durable low-volume road in use in excess of 10 years [21]. Application of the chloride was at a rate of 2 lbs/sq.yd./inch of depth.

Comparative field studies of sodium and calcium chloride were conducted in 1978 by Cornell University [28] on a dense graded low plasticity aggregate surfaced road. Four lbs/sq.yd. of granulated sodium and 1.5 lbs/sq.yd. of a calcium brine were mixed by blade grader, and compacted. Capillary migration of both chlorides to the surface was found extensive, and equal effectiveness of the two products was noted for about 12 weeks.

Magnesium chloride has seen somewhat of an increase in usage over the past few years, but has not received much attention in the literature, other than that provided by producers. As with calcium chloride, magnesium chloride appears viable for dust palliation and stabilization purposes, but laboratory studies on five different soils indicate its effectiveness may also be dependent on humidity and soil type, as well as whether or not it is applied as a spray or used as a mixed-in-place material [26]. Studies by the Swedish Royal Institute of Technology [37], showed that magnesium chloride formed solutions with less moisture than calcium chloride, but required 18% more $MgCl_2$ in order to achieve solutions equivalent to $CaCl_2$ for equal time effectiveness.

Recommended usage of chloride salts for the Pacific Northwest Region, Forest Service, are with dense graded rock having > 6% fines, with or without scarification of the road surface and applied at 0.5-2.5 lb/sq.yd. dry [29]. Preferred application was noted as mixed-in-place.

Kelpak (a two-component product), Clapak/Claset, and SA-1 were highly touted in the early and mid-70's as dust palliative and stabilization agents. In general, they were poorly received for such purposes, and are noted in Table 3 as rating only fair to poor. Laboratory studies of these products with a sandy loam A-2-4(0) soil suggested doubtful effectiveness as dust control/stabilization agents [16].

Over the past 3-4 years an enzymatic product, called Bio-Cat 300, has been promoted in various west and northwest regions of the country for a variety of soils as a compaction, stabilization, and dust control agent. It has been noted by the supplier as increasing cohesive, moisture retention, and density properties [30]. Laboratory tests with an A-6(7), CL soil at 3, 6, and 9 parts per 1000 parts of water by volume, suggested little improvement in potential dust control/stabilization properties [25].

Assessment of the capillary modifiers of Table 3 for use with soils of the Phoenix region and climate, thus suggests a usage potential of only the calcium and magnesium chlorides. Either of these products should probably be looked upon, however, as temporary dust control measures, preferably usable during the winter season, when humidity may be encountered.

Binders

Binding agents of Table 3 include several forms of lignosulfonates, emulsified and cutback asphalts, Coherex, Petro-S, oils, and petroleum resins.

Lignosulfonates are a by-product of the paper pulp industry and are available in several forms depending on the processing used for their extraction. The more common varieties today are calcium and ammonium lignosulfonates, sodium lignosulfonates, and sulfite liquors being scarce. Lignins have been provided with trade names such as Bindtite, Soils Organic Binder, and Norlig, for example. Of importance, however, is the designation modifiers, i.e., calcium and ammonium, since these ions may tend to affect possible exchange reactions with a soil, thus providing variations in product effectiveness with soil type. Lignins have been combined with other chemicals in order to decrease their susceptibility to leaching, increase their binding effectiveness, or potentially increase their load-stability properties; the latter, for example, involved what was termed the chrome-lignin process using a chromate salt, and produced an extremely durable but expensive stabilization product. Other metallic salts and cationic chemicals appeared effective as stabilization agents when combined with lignosulfonates in laboratory testing [34,36]. However, when added with liquid asphalts, asphalt cements or emulsified asphalts, lignins have not appeared as satisfactory stabilization agents according to one investigation [35].

The lignins presented in Table 3 are both of known and unknown varieties as reported in the literature noted. In general however, where applied as a spray to untrafficked or quiescent areas, the lignins apparently provided a reasonable degree of effectiveness. Where spray applied to a roadway in conjunction with an additional chemical, generally positive dust control results were attained. Where used as a road spray application without added chemical, dust control was generally only fair. With or without added chemicals, when lignins were incorporated into soils, longevity of dust control was generally enhanced for at least a period of time, but as a spray may still be susceptible to rainfall leaching.

A lignosulfonate of the Tradename "Dustaside" was applied to a construction haul road in New Jersey in 1984 as a 5:1 dilution and at a rate of 0.2 gal/sq.yd. until 0.17% of residual concentrate was attained in the soil [28]. Results indicated that "in one month over 23,000 Euclids passed over the test section with no complaints of dust from residents." It was also observed that this usage of the lignin "supplanted both watering by distributor truck and later use of calcium chloride."

Roadway spray applications of lignosulfonates were noted as good to fair effectiveness for use in Canada but appeared related to the Province assessed, and quantity of fines on the surface [27]. The type of lignin suggested for usage also varied. For example, calcium lignosulfonate appeared more viable for a wider range of fines content than either the sodium or ammonium variety in British Columbia, but all three varieties were generally of good to fair effectiveness in Manitoba. In Alberta and Saskatchewan, calcium lignosulfonate was generally noted as producing better dust control than calcium chloride.

Lignosulfonates have been recommended for use in the Forest Service, Pacific Northwest Region, at an application rate of 0.2-0.5 gal/sq.yd., with or without scarification, on road surfaces of dense-graded rock, volcanic cinders or pumice, and Mt. St. Helens volcanic ash [29]. Application was noted as being of 50% solids concentration.

Emulsified asphalts presented in Table 3 show a good effectiveness for dust control where incorporated into the soil material; several being noted as ultimately receiving seal coat surfaces. Where utilized as a spray or topical application to road surfaces, the emulsion generally rated fair to poor. Asphalt emulsions may be formulated as cationic, non-ionic, and anionic. Usage of emulsions is therefore dependent on the surface energy, or electrostatic properties of the polar organic emulsifying molecule used in emulsion production, and the resulting absorption at their interface with particulate surfaces. If both the emulsion and soil particles are of similar charges, repulsion occurs and coating and binding action may be severely reduced. Soil/aggregate materials are predominately negatively charged, thereby usually requiring positively charged, or cationic, types of emulsions. Comparative field and laboratory studies of a cationic emulsion, anionic emulsion, and cutback asphalt concluded that the cationic emulsion was superior in coating and adherence abilities with a variety of aggregates, and increased resistance to mechanical stripping and effects of intensive moisture [38].

Soils must be moist prior to application of asphalt emulsions. If dry, most emulsions will break immediately upon contact with the soil particulates, the residual asphalt tending to ball, and effectiveness as either a dust control or stabilization agent being significantly reduced. When utilized as a spray applied surface palliative to a dry soil, pretreatment with water, or water and a surfactant (i.e., the emulsifying agent) may be required for viable results. When applied in the recommended moist state, emulsified asphalts require air curing, in order to permit the water phase to "break," i.e., evaporate.

Asphalt emulsions are generally recommended as mixed-in-place materials. For example, the Pacific Northwest Region, Forest Service, suggests the use of a CSS-I emulsion for mixed-in-place application with a variety of aggregate road surface materials [29]. Spray applications of CSS-I are suggested only for open-graded rock of < 2% minus No. 200 material [29]. However, the Forest Service has utilized emulsified asphalts for dust control on gravel roads through either surface application or modified blade mixing, finding that such usage was advantageous in terms of lack of hydrocarbon volatility and energy conservation [39].

In 1983, a specially formulated CSS emulsion[a] was used as a topically applied product to a non-trafficked construction zone area consisting predominantly of an open-graded fine to coarse sand in Colombia, South America [25]. After 7 months, the crust was still providing essential wind erosion dust control. However, usage of emulsified asphalts as a sprayed-on dust palliative for roadways of < 100 ADT in Saskatchewan are recommended as producing only fair to poor results [27].

Usage of asphalt emulsions may thus include topical spray applications, but such applications may be highly dependent on a low quantity of fines, and the open texture of the surface to which applied.

Cutback asphalts and various oils presented in Table 3 show good to fair effectiveness for several usages with a variety of materials. In most instances, longevity was noted for reasonable periods of time. Most cutback asphalts however, are seeing decreased usage due to increased awareness of volatile hydrocarbons contributing to atmospheric pollution. Most so-called "road-oils" fit such criteria. A number of states in the U.S. have eliminated all usage of cutbacks or road oils for roadway work.

Several "dust oils," denoted by the Pacific Northwest Region, Forest

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[a]Formulated for dilution with seawater.

Service, as DO-1 to DO-6KF, have been recommended for penetration treatment of aggregate surfaced roads ranging from open-graded rock of < 2% passing the No. 200 sieve, to Mt. St. Helen's volcanic ash [29].

In efforts to increase the cohesive and waterproofing properties of cohesionless and clayey sands, the Texas DOT has reported mixed-in-place usage of 4-8% by weight of a medium cutback asphalt [28]. However, they reported that the in-place material must be dry prior to application, and though effectiveness of usage was good for low-volume roads, the additive was not cost-effective.

Due primarily to the environmental effects previously noted, dust oils/ cutback asphalts are not suggested for usage in the Phoenix metropolitan area.

The sunflower oil noted in Table 3 was purely an educated guess application, with no testing or evaluation. Eighteen drums of old oil needed disposal and an adjacent cinders/bottom ash surfaced roadway needed dust control under primary usage of trucks and farm equipment. Constructed in May 1986, the roadway is performing superbly. The usage of such vegetative oils does not appear economically viable [25].

In 1973, a commercial product called Petro-D-Dust, thought to be an unrefined cotton seed oil, was laboratory evaluated as a dust palliative/ surface improvement agent for a sandy loam A-2-4(0) soil [16]. As a mixed-in-place additive at 0.1-0.25% by weight it appeared to have good potential effectiveness, but as a palliative at an application rate of 0.2-0.25 gal/ sq.yd., its potential was noted as fair to poor. No literature regarding field application of this product has been found.

Coherex, Table 3, has been noted by the manufacturer as a concentrated, highly stable emulsion of petroleum oils and resins, consisting of about 60% resins and 40% wetting solutions [5,31]. Of the citations of Coherex in Table 3, effectiveness was good overall. The exception was noted with a double surface spray application in Marion County, Iowa, with a very absorptive roadway aggregate which produced less than one month longevity; much shorter than anticipated. Costs of Coherex, Table 3, were quite variable depending on (1) application rates, and (2) distance from point of manufacture, Bakersfield, California.

Roads and Streets magazine [40], described a program of dust control on heavily traveled, gravel surfaced, plant haul roads, using Coherex as a palliative. A savings was provided in terms of truck time, labor, and use and maintenance with blade graders when compared to use of water only for dust control.

Coherex met dust control expectations of at least two weeks duration on a temporary unpaved access road and yard area when used by the New York DOT [28]. The product was applied as a 1:7 diluted spray, at a rate of 0.5-1.0 gal/sq.yd. on a twelve inch thick crushed slag material of 2 inch maximum size containing less than 10% fines.

During dry weather conditions on roadways consisting of clays to gravels and of less than 100 ADT, spray applied Coherex has been reported as producing fair dust control measures in British Columbia [27]. However, calcium chloride was noted as producing equivalent or somewhat better effectiveness for similar weather and roadway materals conditions.

As a surface applied penetrant treatment, Coherex has been recommended for roadway use by the Pacific Northwest Region, Forest Service, for use with dense-graded rock of greater than 6% passing the No. 200 sieve both with and without initial scarification, volcanic cinders and pumice, and Mt. St. Helen's volcanic ash [29]. Application rates were recommended at 1-1.5 gal/sq.yd. diluted 1:4 Coherex to water.

A soil penetrant, Petro-S, Table 3, has been described as a surfactant consisting of either a solution or powder form of a sodium alkyl ethylene sulfonate [15]. Following a laboratory study it was incorporated as a 6 inch depth field mixed-in-place stabilization/dust control agent in an SC, highly calcitic (caliche) soil near Villanueva, New Mexico, at a concentration of 0.1% by soil weight; the dry powder form having been dispersed in a water tanker prior to application. Stability properties were noted to improve, and dust effectiveness was good at least 2.5 months after construction.

A guar gum based powder called Esi-Duster, that produced a viscous liquid when mixed at 50 lbs/1000 gal. of water was recommended at an application rate of 0.2 gal/sq.yd., without notation as to material type to which applied [29]. An apparently similar guar base derivative was not recommended for mixed-in-place field application with an A-2-6(0) gravelly loam roadway soil when applied dry at a rate of 0.5-2.0% by soil weight [16]. When combined with 2% lignin solids, 0.5 to 1.0% of the guar derivative, called Polymer JB, produced good laboratory results, but was not recommended for field tests with the A-2-6(0) soil due to cost [16].

P/E Additives

The third mechanistic grouping of products in Table 3, i.e., P/E additives, include a wide variety of plastics, polymers, resins, and elastomers, the latter being predominantly of a latex form. While the possible chemical-constituency of many of these products are at least partially described in Table 3, actual chemical makeup is usually more complex than noted, and in some instances is totally proprietary, as may be noted only by the manufacturers/distributors trade names. Included in this group of products are Polybind Acrylic DLR 81-03, Amsco Res AB 1881, Terrakrete No. 2, Surfaseal, Aerospray 70, Curasol AE, Foramine 99-194, Polyvinyl Acetate emulsion, Urethane liquid, copolymer of methacrylates and acrylates, latex emulsion, petroleum resin emulsion, and Corexit 178.

With four exceptions all of the P/E products are noted in Table 3 as having been spray applied; the Corexit 178, polyvinyl acetate emulsion, and copolymer of methacrylates and acrylates having been both sprayed and mixed-in-place, and the urethane mixed to a depth of less than 0.5 inch. Of the spray applications of these products, twelve were noted from the literature as producing good effectiveness, five as fair, and only the Amsco Res AB 1881 as poor; the latter lasting less than two weeks on a low-volume county roadway.

Of the spray-applied P/E products showing good to fair effectiveness in Table 3, longevity appeared to vary, but was generally of good duration. Variations of longevity of effectiveness appeared related to three conditions of observance of the treated roadways and/or quiescent areas; (1) no further observations or in-situ testing was conducted, (2) the product had fulfilled its anticipated expectation of control needs, or (3) the product showed failure after the period of effectiveness noted.

Soils with which the P/E grouping of products of Table 3 were utilized, ranged from gravel and sands, to finer grained clayey materials and mine tailings, though with several of the literature citations, the soils were not described. Purpose of soil treatment with each of these products varied from roadway and haul road dust control, to control of dust on non-trafficked or quiescent areas, wind erosion, slope and spoil bank erosion, and mine tailings and pond dust. In order to achieve this diversity of purpose of treatment through spray application only, those products producing good effectiveness had to provide a continuing interacting matrix, or aggregation, of fine particulates at the surface, as well as a partial penetration of loose surficial particulates to bond to an underlying base.

Where reported, the P/E products of Table 3 ranged in cost from about \$0.06/sq.yd. to \$1.59/sq.yd. In most instances such costs involved only the product, labor or equipment was not included. The variability of costs should be considered in the context of dilution and application rates, as well as the point of time at which such costs were reported.

Where spray applied for roadway dust control, Aerospray 70, Curasol AE, Foramine 99-194, Polyvinyl acetate emulsion, and Corexit 178 appeared as viable palliatives, Table 3. Where spray applied for purposes of dust control on untrafficked or quiescent areas, Terrakrete No. 2, Surfaseal, and Corexit 178 appeared as viable agents. Where Spray applied primarily as slope or water erosion products, polyvinyl acetate emulsion, urethane liquid, copolymer of methacrylates and acrylates, and latex emulsion appeared as viable products. Corexit 178, copolymer of methacrylates and acrylates, and polyvinyl acetate emulsion, appeared to produce satisfactory effectiveness ratings when mixed-in-place, regardless of purpose of treatment.

While not presented in Table 3, Corexit 178 was field trialed as both a spray applied quiescent and mixed-in-place dust control agent, as well as a slope erosion control agent in Colombia, South America, and was reported as producing viable effectiveness for both treatment purposes in a silty sand soil [25]. Soil Seal (Table 2) and Corexit 178 have also been used in Colorado for prevention of wind erosion of spent oil shale disposal dumps, and have been reported as viable products for such usages [25].

Epoxy resins have been laboratory evaluated as soil stabilization agents for use where trafficability under heavy loads must be accomplished in a short time span, without susceptibility to water, oils, or other hydrocarbons [32]. When cured, epoxy resin is an inert solid. Tried with a range of four soils varying from a dune sand to an A-7-6(18) silty clay, the epoxy resins were noted to produce excellent stability and very low water susceptibility when mixed at about 3% by weight with the more sandy soils, but were not as satisfactory with the higher clay content soils. These products were not put to field trials due to cost, but are presented herein as illustrating that many products not normally thought of as being applicable for soil stabilization, surface improvement, erosion control, or dust control purposes may actually have potential viability in such soil usages.

A water miscible proprietary polyester resin, Stypol 40-5020, was laboratory evaluated as a dust palliative/surface improvement agent with an A-2-4 sandy loam soil and was recommended for field trials at a rate of 0.5% by weight [16].

Polymeric products have been utilized for soil stabilization studies for many years. In an extensive laboratory search for a chemical product which could solidify a range of soils from sands to clays, a laboratory investigation utilized a calcium acrylate monomer, polymerized with a redox catalyst and mixed with the soils to form a flexible product having significant tensile strength and withstanding deteriorating effects of water [41]. Utilizing from 10 to 20% by weight of such product, it was recommended for a number of applications, including temporary and access roads, but was noted as extremely expensive. In a further study of acrylate polymer products [42], it was noted that up to 0.1% by weight of a sodium polyacrylate could increase strength and induce aggregation of soil particles. Significant aggregation of soil particles was also noted in a laboratory investigation of three organic polymers with soils ranging from an A-1-b to an A-6 [8]. Satisfactory polymer contents were of the range of 0.1-0.3% by soil weight.

At soil concentrations of 5-10% by weight, acrylic polymers were found to create strong water resistant soil/composite systems [43]. Soil strengths were observed to increase over a period of 10 days, due to processes associated with evaporation of moisture and hardening of the polymers [43].

Soils treated with 0.1% polymer solutions for purposes of reinforcement were noted to provide improved compressive strengths without reducing soil permeability [44]. A further study confirmed these results, and extended the application of polymer soil treatments to wind and water erosion control, where such resistance was increased considerably in terms of time, as well as providing protection of the soil until vegetative cover was achieved [45].

A study of polymer stabilization of sandy soils for control of wind and water erosion indicated spray application required less product, and provided better erosion resistance than mixed applications [46]. Test results indicated good erosion control did not necessarily provide high soil strengths, and that changes in soil/polymer characteristics brought about from water intrusion, indicated polymer stabilization for water erosion was not as successful as for wind erosion applications. The study also concluded that water based polymer emulsions were preferred over alcohol-based polymers.

In summary, P/E agents appear to provide desirable dust control and stabilization effectiveness with a variety of soils. In general, such products, on a unit cost basis, are expensive. However, they have generally been utilized at very low soil concentrations, thus making such products economically viable for dust control practices.

PRODUCT RECOMMENDATIONS FOR PHOENIX AREA SOILS

Perusal of Tables 2 and 3, plus the text of the preceding section of this report, suggests that many dust control products may be soil or site specific. Product A may provide good effectiveness in location X with soil classification SC, but when tried in location Y with the same SC classified soil, the product may have been rated only fair to poor. Portions of the reasons for such variation in effectiveness have been presented in the "Summary of Mechanism of Dust Control" section of this report as well as with several of the products in relation to their individual mechanistic groupings.

It is therefore assumed that in any initial dust control field experimentation, the Arizona DOT would prefer to examine and/or evaluate a short listing of products which are judged herein as providing potential dust control to the widest possible variety of Phoenix metropolitan area soils. If accepted, such products could then be put into immediate practice, with additional product evaluations to commence thereafter. It is also assumed that in any initial field experimentation, both longterm and temporary measures of dust control should be considered.

With the aforementioned assumptions clearly in mind, of the products presented in the previous sections of this report, four binder and P/E agents are recommended as probably having the most immediate applicability in the Phoenix area as based on potential longevity, area soil properties, and general product potential. These products are:

- CSS-I asphalt emulsion, of at least light cationic variety, not non-ionic.
- Coherex.
- Corexit 178.
- Soil Seal.

While the recommendation of these products is based on the examination of both soils and products presented in this report, such recommendations are also a matter of objective judgment on the part of the writer. However, it is these products which appear to have the greatest potential to be placed in immediate field trials, without requiring considerable laboratory evaluation.

In addition, each of the four products is available today; many of the other binders and P/E products are of questionable availability. Each of the four appears to provide reasonable longevity of control with a relatively wide range of soils for topical application to quiescent areas. With the exception of Soil Seal, the remaining three products appear to provide reasonable longevity of control with a variety of soils for mixed-in-place applications under possible vehicular loadings; the dominant usage of Soil Seal having been in quiescent dust control or erosion applications.

For temporary dust control measures, the capillary modifiers of calcium and/or magnesium chlorides are recommended as having the most immediate applicability for soils of the Phoenix area. As noted previously however, the low humidity of the region may tend to affect usefulness of these products as even temporary dust control agents, possibly limiting their usability to winter seasons when greater humidity might be anticipated.

Products which should be considered for future evaluation are predominantly of the binder or P/E mechanistic groupings, with primary application emphasis as mixed-in-place to a minimum 2 inch depth. Recommended are ammonium lignosulfonate and one or more of the plastic and elastomeric products, such as the polyvinyl acetate, urethane, and latex emulsions.

Development of any detailed field trials, budget, impact statement, objectives for implementation, and follow-up investigations or monitoring, are beyond the scope of the preceding recommendations of this report. This is due to the fact that implementation of such recommendations must initially be coordinated with a specific site, or sites, the soil characteristics thereof, and the anticipated construction project plans, processes, and specifications being considered therein.

A primary consideration for proceeding with implementation of the preceding recommendations however, is the potential cost effectiveness of such products versus continuing watering operations. A few illustrations of cost are thus in order. Product, equipment, and labor costs used in the following illustrations may or may not be specifically applicable to the Phoenix area but are assumed for illustrative purposes only.

Water tanker--spray bar equipped ----------------	\$ 38/hr
Tanker equipped with nurse feed to mixer --------	\$ 45/hr
Motor grader with scarifier teeth ---------------	\$ 55/hr

Travel-plant mixer, with feed pump and spray bar	$190/hr
Pneumatic tire roller	$ 40/hr
Vibratory roller	$ 45/hr
Laborers	$ 12/hr
Supervisor	$ 25/hr

Anticipated longevity with product treatment:

Non-trafficked quiescent areas	6 months
Spray applied haul roads	2 weeks
Mixed-in-place haul roads, 4 inch depth, with surface maintenance and product rejuvenation at 2 week intervals	3 months

Water and product costs:

Water (includes equipment and operator costs)	$8/1000 gallons[a]
Asphalt emulsion	$0.65/gallon
Chemical	$5.00/gallon

For non-trafficked quiescent areas consisting of one acre or 4840 sq.yds., it was assumed that water only would be applied twice daily at a rate of 1.0 gal/sq.yd., for a total daily cost of $77. For comparison over the 6 month anticipated longevity of a chemical treatment, the cost of water was thus estimated at $13,939. A 10% active chemical costing $5.00/gal., diluted in water, with the dilution applied at 1 gal/sq.yd. in order to provide 0.1% by soil weight at one inch of penetration, was estimated to require 566 gal. of product, and 4274 gals. of water, for a total cost of $2864. Anticipated equipment and laborers for this product application assumed a 5-hour operation involving a water tanker/sprayer, motor grader, pneumatic tire

[a]As received from Mr. Steve Tritsch, ATRC

roller, 2 laborers, and 1 supervisor, or $182/hr, for a total of $910. Total estimated cost, with possible 6 month longevity, was thus $3774, or less than 30% of the estimated cost of water only.

The area of dust control coverage for a spray applied haul road was assumed as 28 ft. width and one mile length. If water were applied hourly over a 10 hr. day at a rate of 1.0 gal/sq.yd., cost of such an operation was estimated at $1314/day. For comparison with the assumed two week longevity of a surface applied chemical, water costs for the 14 day period would be $18,398. If it were also assumed that water application would require blade grading of 2 hrs/day for the 14 days, an additional $1540 of equipment costs would raise the total estimate to $19,938. Assuming an average depth of penetration of 1 inch, the $5.00/gal chemical needed at 0.1% soil weight, and applied in a diluted form at the rate of 1.0 gal/sq.yd., the haul road would thus need 1920 gal. of product and 14,507 gals. of water at a combined cost of $9716. Equipment and labor utilized would be the same as for the non-trafficked area, $182/hr., but for a period of 10 hours, or a cost of $1820. Total product/equipment/labor estimated costs would thus be $11,536, or about 63% the costs of water and blading over a possible two week span of longevity.

In the following cost estimates for two products mixed to a depth of 4 inches, no estimate of water was included with either, since quantity would be dependent on the optimum moisture content for maximum densification and could vary considerably between the two products. A CSS-I asphalt emulsion, at an assumed residue content of 57%, was introduced to the soil at 4% residual, or about 7.0% total emulsion. Length and width of the haul road was again 5280 ft and 28 ft, respectively. Quantity of emulsion was estimated at 53,233 gals., for a cost of $34,602. Equipment and labor was estimated for two 10-hr. days and included a travel-plant mixer, motor grader, water tanker with nurse feed to mixer, vibratory compactor, pneumatic tire roller, 3 laborers, and one supervisor, or $436/hr, for a total of $8720. It was also assumed that every two weeks for the three month anticipated longevity, a 1:6 emulsion to water dilution would be required as a surface dressing, applied at a rate of 0.25 gal/sq.yd. Utilizing a 3 hr. operation of blade grader, pneumatic roller, tanker, 3 laborers, and a supervisor, the costs would be about $2670 for the emulsion, and $3618 for equipment and personnel, or a total of $6288. Thus for an anticipated longevity of 3 months, it was estimated that the CSS-I asphalt emulsion mixed-in-place application would cost about $49,610.

Using the same length, width, and mixed-in-place depth criteria with the chemical, applied at 0.1% by soil weight, estimated cost of the product was initially $38,022. Equipment and personnel for initial construction would add about the same cost as with the asphalt emulsion, or $8720. As a surface dressing each 2 weeks of the 3 month anticipated longevity, to revitalize the surface chemical to the 0.1% by soil weight concentration, costs of the chemical were estimated at $20,550, using a 1:6 dilution of chemical to water, applied at a rate of 0.25 gal/sq.yd. Equipment and personnel for the periodic surface dressing were assumed equal to the emulsified asphalt, or $3618. Total costs were therefore $70,910 for the 3 month period.

For comparative purposes with the asphalt emulsion and chemical mixed-in-place estimated costs, water application was assumed for the 3 month period at once per hour, 10 hrs/day, over the same length and width of haul road, for $118,260. A two hour daily blade operation was estimated at an additional $9900. Total comparative cost was thus estimated at $128,160, or about 2.5 times the estimate for the asphalt emulsion, and about 1.8 times greater than the chemical; both relative factors should be reduced, however, when cost of water for attaining optimum moisture content is included.

The preceding cost estimates illustrate the potential validity of use of dust control agents versus water operations within construction zones from an economic standpoint. It should be obvious however, that prices selected for each item within these illustrations may vary from those actually achieved during a field trial and follow-up investigation. For example, the four recommended binder and P/E agents may very well be higher or lower in their delivered costs to the Phoenix area than used within each illustration. In addition, rates of water application may vary in terms of construction site location and soil type, and may thus be higher or lower than utilized in each illustration. Regardless of such variations, from an economic and environmental point of view, the usage of dust control agents on construction sites in the Phoenix metropolitan area appears to demand field evaluation.

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